Packstock and Backpack Use in Wilderness: Regulation Frequency and Relative Use Levels

FINAL REPORT FOR RESEARCH JOINT VENTURE AGMT
#INT-89411-RJVA with
UNIVERSITY OF ARIZONA
FS Contact: David Cole
CO-OP Contact: Mitchel P. McClaran

Packstock and Backpack Use in Wilderness: Regulation Frequency and Relative Use Levels

31 October 1993

Mitchel P. McClaran and Steven D. Moore

School of Renewable Natural Resources
University of Arizona, Tucson AZ 85721

Submitted to U.S. Forest Service Intermountain Research Station

Final Report for Cooperative Joint Venture Agreement INT-89411-RJVA
State-of-Knowledge About Packstock Management in Wilderness/Backcountry

How comparable are the frequencies of regulations controlling packstock and backpack use in wilderness? A logical prediction is frustrated by the contradiction of greater research and management attention to control backpack impacts (Cole 1990), but greater per user impact from packstock (Cole 1990) and a high frequency of some types of packstock use regulations (Washburne and Cole 1983; McClaran and Cole 1993). Our research compares the frequency of six regulations that can be applied to both packstock and backpack use, and we limit the comparison to wilderness areas where packstock and backpack use both occur. This effort does not compare the scale of regulation (i.e.specific control level or severity of penalties), it only compares the presence of regulations.

Problems from packstock and backpack use are generally the result of impacts to trails, campsites, other visitors, wildlife and water quality. Per

user impacts to trails, campsites and other visitors are typically several magnitudes greater for packstock than backpack use; while a similar pattern is suggested for impacts to wildlife and water quality, there is no supporting research or documentation (Cole 1990; McClaran and Cole 1993). Furthermore, packstock impacts to grazing areas through trampling and defoliation have no backpack analog (Cole 1990; McClaran and Cole 1993).

Over the last decade, wilderness managers perceived a persistently high degree of impact to trails, campsites, grazing areas, other visitors, wildlife and water quality. In 1980, the frequency of areas where wilderness managers perceived many problems from these impacts was remarkably high: 26% for trails, 33% for campsites, 18% for packstock impacts, 13% for visitors through crowding, 3% for other visitors through conflicts, 6% for wildlife, and 2% for water quality (Cole et al. 1987). In 1987, the frequency of Forest Service areas where managers described moderate or greater impacts showed no sign of diminished problems: 39% for trails, 32% for campsites, 25% for visitors through crowding, 16% for other visitors through conflicts, 9% for wildlife, and 9% for water quality (United States General Accounting Office 1989).

From the array of management practices that can control the severity of impacts to these resources and other visitors (Cole et al. 1987; Cole 1989), we chose six practices to compare the frequency of application between packstock and backpack use because they are have similar applicability to both uses. These six practices; party size, length of stay, camp away from streams/lakes, stay on trails, total use, and season of use are recognized methods to control these impacts (Table 1).

These control measures can be applied as regulations, suggested guidelines or simply included in informational brochures about wilderness visitation. Their application as regulations has been viewed as a last resort that should be applied at minimum levels because regulations can infringe on the visitor's wilderness experience (Hendee et al. 1990; Lucas 1982, 1983). However, it has been suggested that instituting regulations before problems become unacceptable is more equitable and effective because only conscientious visitors will comply, and the reduction in impacts from conscientious behavior will be negated by the behavior of less-conscientious visitors (McAvoy and Dustin 1983). The frequency of regulations is much greater in National Park Service than Forest Service areas (Washbourne and Cole 1983; McClaran and Cole 1993), and the respective managers perceive the utility of regulations quite differently (Bury and Fish 1980; Fish and Bury 1981). Agency management styles are stereotyped as Forest Service managers preferring to promote educational programs initially, and resorting to regulations when problems exceed acceptable levels; while National Park Service managers prefer to institute regulations more quickly to prevent impacts before they become unacceptable. This stereotype is consistent with differences in the Code of Federal Regulations. Forest Service (36 CFR 293.3, 1992) and Bureau of Land Management (43 CFR 8560.1-2, 1992) directives simply permit the authorized officer to regulate backpack or packstock use, whereas, National Park Service (36 CFR 2.10 and 2.16, 1992) specifically prohibit camping near streams/lakes or non-designated areas, off-trail travel with packstock or loose-herding packstock unless permitted by the Superintendent. In addition, authority is given to the Superintendent to regulate other aspects of packstock and backpack use.

Based on the above characteristics of propensity to regulate and relative severity of packstock and backpack impacts, we propose these expected findings a comparison of the frequencies of these six packstock and backpack use regulations. Packstock regulations should be more frequent for packstock than backpack use. Regulations should be exclusively applied to packstock use when the relative proportion of packstock use is high, and regulations should be applied exclusively to backpack use when the relative proportion of packstock use is low. Finally, the frequency of packstock and backpack use regulations should be greatest for wilderness areas under National Park Service management.

Methods

To describe the frequency of regulations and the relative proportion of packstock and backpack use in wilderness areas with both packstock and backpack use, we used responses to a mail-back questionnaire that was sent to over 440 areas, virtually every unit in the National Wilderness Preservation System, in January 1990 (Moore and McClaran 1991; McClaran and Cole 1993). Ten U.S. Fish and Wildlife Service areas were excluded because their limited size and remote location, precludes or severely limits visitation. The questionnaire was addressed to the manager with discretionary authority for wilderness at the following administrative levels: Forest Service Ranger District, National Park or Monument, Bureau of Land Management Resource District and Fish and Wildlife Service Refuge. In the Forest Service, it is common for more than one district or forest to share responsibility for a wilderness area. In these cases, the questionnaire was sent to only one Ranger

District, usually the one with responsibility for the greatest proportion of the wilderness. Some Forest Service Ranger Districts received more than one questionnaire because they administered several wilderness areas; nowever, only one questionnaire per wilderness was mailed to a given Ranger District. Therefore, each wilderness is represented by one questionnaire, and a questionnaire represents at least a portion of a single wilderness. Three follow-up mailings (Dillman 1978) encouraged prompt responses and a 96% return rate.

The questionnaire solicited responses about the proportion (%) of total use (e.g. visitor days) contributed by packstock (day and overnight) and backpack (day and overnight), and the status of regulations used to control impacts from these two uses. The status of regulations was described by a yes or no response to a list of regulations (including party size, length of stay, camp away from streams/lakes, stay on trails, total use, and season of use). In the questionnaire, and throughout this paper, regulations refer to directives that require specific user behavior and have the force of law; where violators can be fined, expelled or prohibited from re-entry. To reduce any influence on the manager's responses, we presented questions at the beginning of the questionnaire and backpack questions were presented much later and last.

Responses from Fish and Wildlife Refuges are not presented because only two areas had both packstock and backpack use.

We describe the relative abundance of these two uses by calculating the

ratio of total packstock use (day and overnight) and total backpack use (day and night).

We used three criteria to assess the expectations that regulations should be applied more frequently to packstock use: a) the frequency of exclusive packstock regulation (packstock only) should be greater than exclusive backpack use regulation (backpack only), b) the frequency of exclusive packstock use regulation should be greater than regulation of both uses, and c) the frequency of any packstock use regulation (packstock total) should be greater than any backpack use regulation (backpack total).

We used three criteria to assess the expectations that regulations should be exclusively applied to packstock use when the relative proportion of packstock use is high, and regulations should be applied exclusively to backpack use when the relative proportion of packstock use is low: 1) the ratio of packstock to backpack use should be highest when the regulation is applied exclusively to packstock, 2) the ratio of packstock to backpack use should be lowest when the regulation is applied exclusively to backpack use, and 3) the ratio of packstock to backpack use should be higher when the regulation is applied exclusively to packstock use than areas where no regulations are present. Rationale for criteria 1 and 2 are more obvious than for criteria 3. Criteria 3 uses the ratio for areas without the regulation as a null model to judge the relationship between exclusive packstock regulation and the use ratio. Analysis using these criteria was not possible for Bureau of Land Management areas because of the small sample size and low frequency of regulation. Some of these criteria could not be applied to National Park

Service areas because no areas had exclusive application of regulations or all areas regulated both uses.

Results

Trail only and season of use regulations were more frequent for packstock than backpack use (Table 2). Only Forest Service regulation of total use and camping by streams/lakes was generally more common for packstock than backpack use. Only National Park Service regulation of length of stay was slightly greater for packstock than backpack use. Regulations in Bureau of Land Management areas was very low or absent for both uses, and the same regulation was never used to control impacts from both packstock and backpack use in any wilderness.

The expected relationship between exclusive regulation of either use and the relative proportion of packstock and backpack use was supported in slightly more than half (14 of 25) of the evaluations, and five of the eleven failing evaluations had opposite outcomes than expected (Table 3). The expected outcome was most common for regulations addressing camping near stream/lakes, season of use and length of stay. These regulations generally conformed to the three criteria, but the null model (criteria #3) failed for season of use. The use ratio-regulation relationship had an opposite outcome than expected for party size regulation in National Park Service areas and trail-only regulation in Forest Service areas.

The National Park Service generally had the greater frequency of areas

with these six regulations, and the Bureau of Land Management generally had the lowest frequency (Table 2). This pattern was repeated for regulations directed at both packstock and backpack use, and regulations exclusively applied to either use. However, the Forest Service had the greatest proportion of areas with opening date regulations for backpack use, and total use and camping near streams/lakes regulations exclusively applied to packstock use.

Party size, length of stay and camping near streams/lakes were the most common regulations controlling packstock and backpack use (Table 2). Season of use was the least common regulation for both uses.

The relative proportion of packstock use was highest in Forest Service areas, and it was slightly higher in National Park Service than Bureau of Land Management areas (Table 2).

Discussion

In general, packstock use garners less frequent regulatory attention than backpack use in wilderness areas where both uses occur, and exclusive regulatory attention to packstock use usually exists where the relative proportion of packstock use is high. Previous studies show high frequencies of packstock regulation (Washbourne and Cole 1983; McClaran and Cole 1993), but a comparison with our findings must recognize that we only evaluated the frequency of six regulations that can be applicable to both uses. The previous studies were not limited to jointly applicable regulations, instead, these studies included packstock use regulations such as tying stock to trees and

carrying weed-free feed that have no backpack analogs.

When packstock use attracts more frequent regulatory attention, the relative packstock and backpack use levels and resource impact literature can rationalize that action. However, in most cases, documentation of greater per user impact in the resource impact literature is not sufficient justification to apply these regulations to packstock use exclusively unless packstock use is relatively high. Instead, the typical application of regulations to packstock use appears to be done in concert with backpack use regulations, so that a particular regulation applies to both users.

Season of use and trail restriction are the main exceptions to the general pattern of less frequent packstock use regulation, and the resource impact literature supports these exceptions. Off-trail packstock use results in faster and more serious vegetation and soil impacts than backpack use (Cole 1990). Similarly, packstock grazing when soils are wet and plants are in early phenological stages can lead to impacts that have no backpack analog (McClaran and Cole 1993). However, research findings are the least likely source of information used to formulate season of use regulations for packstock use; while tradition, professional judgement and production livestock standards are most common sources for formulation (McClaran and Cole 1993). This seeming disparity may result because the resource impact literature is too general to assist in the formulation of site-specific regulations, but it is relevant enough to alert managers to potential problems and solutions.

The relationship between relative use levels and exclusive packstock or

backpack use regulations conform to expectations for higher season of use regulation for packstock use, but not for trail restriction. Apparently, trail restriction is being applied as a preventative tool.

The National Park Service continues to use regulations more frequently than the other wilderness agencies, and this generally applies to packstock and backpack uses. The stereotypic view of preventive management in National Park Service areas and corrective management in Forest Service areas is particularly evident in the regulation of packstock use. The relative proportion of packstock use in considerably higher in Forest Service areas, but packstock use regulation is typically more frequent in National Park Service areas. An apparent exception to this pattern is the greater frequency of exclusive packstock use regulation for camping away from streams/lakes. However, because all National Park Service visitors are required to camp away from streams/lakes (36 CFR 2.10, 1992) unless otherwise permitted, exclusive regulation of either use is unlikely. The Bureau of Land Management appears to be more selective in the application of these regulations than the other agencies: regulations are rarely applied and no regulation is applied to both packstock and backpack use in any area.

The relatively high popularity of party size, length of stay and camping away from streams/lakes regulations; and low popularity for trail restriction, total use and season of use regulations continues a historical trend that started in 1978 (Fish and Bury 1981; Washbourne and Cole 1983; United States General Accounting Office 1989). Party size regulations are now more frequent on National Park Service areas, less frequent on Bureau of Land Management

areas, and are largely unchanged on Forest Service areas. Similarly, the frequency of party size regulations has remained similar for packstock and backpack use over this time period. Length of stay regulations have increased in frequency in areas administered by the Forest Service and National Park Service, but the Bureau of Land Management has never applied this regulation. Total use, season of use and camping away from streams/lakes regulations have become more frequent on National Park Service areas, but have changed much less or are unchanged for the other agencies.

Unfortunately, it is not possible to assess the outcome of this general increase in wilderness use regulation from our analysis and data. However, some authorities have compared the relative effectiveness of these control methods (Cole et al. 1987; Cole 1989). The high amount of attention to party size and camping away from streams can be effective in preventing impacts, especially impacts to other visitors and impacts that occur quickly and with small amounts of use. However, length of stay regulations have been criticized because they are generally 2-3 times longer than the average visit, and therefore only address homesteading behavior. The low frequency of total use and season of use regulations may reflect the requirement of site-specific standards to be effective because wilderness-wide approaches tend to simply hamper visitors without improving conditions. In addition, because these two control measures tend to infringed more heavily on wilderness users than the other regulations and they require a significant research and development effort, it is not surprising that they are the least commonly applied.

Finally, although this paper describes differing regulatory attention to

packstock and backpack use and changing historical attention, it should be clear that use regulation is not the only approach to controlling visitor impacts in wilderness (Hendee et al. 1990). In fact, suggested guidelines and location of trails and camping areas/facilities are generally more common for packstock use than regulations, except in the few areas administered by the National Park Service. (McClaran and Cole 1993). However, it is likely that the frequency of regulations will increase because over 40% of wilderness managers perceive an inadequate level of regulation to control impacts from packstock use (McClaran and Cole 1993).

Literature Cited

36 Code of Federal Regulations 2.10. 1992. Camping and food storage. Department of Interior National Park Service.

36 Code of Federal Regulations 2.16. 1992. Horses and pack animals. Department of Interior National Park Service.

36 Code of Federal Regulations 293.3. 1992. Control of uses. Department of Agriculture Forest Service.

43 Code of Federal Regulations 8560.1-1. 1992. Permits for and restrictions on use. Department of Interior Bureau of Land Management.

43 Code of Federal Regulations 8560.1-2. 1992. Prohibited acts. Department of Interior Bureau of Land Management.

Bury, Richard L. and C. Ben Fish. 1980. Controlling wilderness recreation: what managers think and do. Journal of Soil and Water Conservation 35:90-93.

Cole, David N. 1989. Low-impact recreational practices for wilderness and

backcountry. USDA For. Serv. Gen. Tech. Rep. INT-265. 131 p.

Cole. David N. 1990. Ecological impacts of wilderness recreation and their management. In, John C. Hendee, George H. Stankey and Robert C. Lucas. Wilderness Management. 2nd. Ed. Fulcrum Publishing Company, Golden, Colorado. pp. 425-466.

Cole, David N., Margaret E. Petersen and Robert C. Lucas. 1987. Managing wilderness recreation use: common problems and potential solutions. USDA For. Serv. Gen. Tech. Rep. INT-230. 60 p.

Dillman, Don A. 1978. Mail and Telephone Surveys: The Total Design Method. John Wiley and Sons, New York.

Fish, C. Ben and Richard L. Bury. 1981. Wilderness visitor management: diversity and agency policies. Journal of Forestry. 79:608-12.

Hendee, John C., George H. Stankey, and Robert C. Lucas. 1990. Wilderness Management. 2nd. Ed. Fulcrum Publishing, Golden, Colorado. 546 p.

Lucas, Robert C. 1982. Recreation regulations-when are they needed? Journal of Forestry 80:148-51.

Lucas, Robert C. 1983. The role of regulations in recreation management. Western Wildlands 9(2):6-10.

McAvoy, L.H. and D.L. Dustin. 1983. Indirect versus direct regulation of recreation behavior. J. Park & Recreation Administration 1:12-17.

McClaran, Mitchel P. and David N. Cole. 1993. Packstock in wilderness: use, impacts, monitoring, and management. USDA For. Serv. Gen. Tech. Rep. INT-301. 33 p.

Moore, Steven D. and Mitchel P. McClaran. 1991. Symbolic dimensions of the packstock debate. Leisure Sciences 13:221-37.

United States General Accounting Office. 1989. Wilderness preservation. GAO/RCED 89-202. 91 p.

Washburne, Randel F. and David N. Cole. 1983. Problems and practices in wilderness management: a survey of managers. USDA For. Serv. Res. Paper INT-304. 56 p.

Table 1. Predominant impacts from packstock or backpack use in wilderness and the some of the suggested methods to control those impacts (adapted from Cole et al. 1987; Cole 1989).

Control Method	Packstock or Backpack Use Impacts					
	Trails	Camps	Grazing Areas	Visitors	Wildlife	Water Quality
Party Size	X	X	X	X	X	
Length of Stay		X	X		X	
Camp Away From Lakes/Streams				X	X	X
Stay on Trails	X	X			X	
Total Use			X	X	X	
Season of Use	X		X		X	

Table [illegible]. Frequency of regulations and ratio of packstock to backpack use for wilderness areas administered by the Forest Service (FS), National Park Service (NPS) and Bureau of Land Management (BLM).

			REGULATION APPLIED TO											
			NO USERS		PACKSTOCK TOTAL		PACKSTOCK ONLY		BOTH USERS		BACKPACK ONLY		BACKBACK TOTAL	
REGULATION	AGENCY	N	%	ratio	%	ratio	%	ratio	%	ratio	%	ratio	%	ratio
Party Size	FS	164	46	.48	45	1.37	5.7	.78	40	1.44	10	.29	49	1.21
	NPS	8	0		75	.15	13	.14	63	.15	25	.51	88	.25
	BLM	7	86	.18	0		0		0		14	.01	14	.01
Length of Stay	FS	164	51	.56	36	1.46	3	1.43	33	1.47	13	.33	46	1.15
	NPS	8	0		100	.24	25	.37	75	.19	0		75	.19
	BLM	8	100	.19	0		0		0		0		0	
Camp Away from Streams/Lakes	FS	165	52	.78	42	1.03	9	2.78	33	.58	7	.17	40	.51
	NPS	7	14	.02	86	.15	0		86	.15	0		86	.15
	BLM	8	88	.21	0		0		0		13	.08	13	.08
Stay on Trails	FS	165	92	90	7	.21	6	.19	1	.29	1	4.3	2	.34
	NPS	7	0		100	.13	71	.17	29	.04	0		29	.04
	BLM	8	88	.16	13	.45	13	.45	0		0		0	
Total Use	FS	165	95	.88	4	.45	2	.63	1	.09	2	.12	3	.11
	NPS	8	50	.44	13	.05	0		13	.05	38	.03	50	.04
	BLM	8	100	.19	0		0		0		0		0	
Season of Use	FS	163	96	.89	4	.29	3	.30	1	.29	1	.12	2	.23
	NPS	8	75	.31	25	.04	25	.04	0		0		0	
	BLM	7	100	.19	0		0		0		0		0	

Table 3: Relationship between exclusive packstock or backpack regulation and the ratio of packstock and backstock use using three criteria for Forest Service and National Park Service areas. Criteria 1 - the ratio should be highest when the regulation is applied to packstock only. Criteria 2 - the ratio should be lowest when the regulation is applied to backpackers only. Criteria 3 - the ratio should be higher when regulation is applied to packstock only than areas where no regulations are present. (FS = Forest Service; NPS = National Park Service; NP = not possible to apply criteria).

		Criteria		
Regulation	Agency	1	2	3
Party Size	FS	fail	pass	pass
	NPS	opposite	opposite	NP
Length of Stay	FS	fail	pass	pass
	NPS	pass	NP	NP
Camp Away From Lakes and Streams	FS	pass	pass	pass
	NPS	NP	NP	NP
Stay on Trails	FS	opposite	opposite	opposite
	NPS	pass	NP	NP
Total Use	FS	pass	fail	fail
	NPS	NP	pass	NP
Season of Use	FS	pass	pass	fail
	NPS	pass	NP	fail

The University of
Montana

School of Forestry / Montana Forest
& Conservation Experiment Station
Missoula, Montana 59812-1063
(406) 243-5521
FAX (406) 243-4510

Dr. Stephen F. Arno
Intermountain Research Station
Intermountain Fire Sciences Laboratory
P.O. Box 8089
Missoula, MT 59807

14 August, 1993

Dear Steve:

Enclosed is the final report for INT/UM Joint Venture Agreement No. INT-92683-RJVA. This report summarizes long-term growth trends in the six old-growth ponderosa pine/Douglas-fir stands for which you are doing a detailed stand structure analysis. More specifically, the report includes an analysis and interpretation of long-term growth trends in the two stands with fire and the four stands without fire since 1900, based on your fire history analysis.

I appreciate having the opportunity to work with you on this project Steve, and look forward to continued cooperative work in the future.

Sincerely,

Carl

Carl Fiedler
Research Assistant Professor, UM

FINAL REPORT
University of Montana/INT Research Joint Venture Agreement
INT-92683-RJVA

Carl Fiedler, School of Forestry, UM
and
Brian Steele, Department of Mathematical Sciences, UM

Long-Term Growth Trends in Old-Growth Ponderosa Pine/Douglas-fir Stands With and Without Fire

INTRODUCTION

Considerable attention has been focused on old-growth ponderosa pine (Pinus ponderosa) forests over the years, beginning with early descriptive accounts (Leiberg 1899; Ayres 1900; Pearson 1910) to more recent work aimed at such issues as successional trends (Lunan and Habeck 1973; Moir and Dieterich 1988; Keane et al. 1990), fire history (Weaver 1959; Arno 1976), age-class structure (Cooper 1960; Arno and Scott 1992) prescribed burning effects on soil nutrient status (Ryan and Covington 1986; Covington and Sackett 1990), and management needs -- particularly the reintroduction of fire (Arno and Brown 1989, Habeck 1990). To date, however, there have been few investigations of the short-term effects of fire on growth rates of ponderosa pine (e.g. Van Sickle and Hickman 1959; Landsberg et al. 1984), and virtually no studies of the relationship of long-term growth (30-50 yrs) with fire.

Prior to European-American settlement of the Rocky Mountain West, ponderosa pine/Douglas-fir (Pseudotsuga menziesii var.

glauca) stands were exposed to frequent surface fires. Lightning and Native American ignitions were primary sources of these fires (Barrett and Arno 1982). In western Montana, settlers began suppressing fires around 1900. Consequently, the density, relative species composition, and structure of old-growth pine-fir stands today differ dramatically from turn-of-the-century descriptions (Leiberg 1899; Ayres 1900). These long-term effects of fire suppression are clearly evident, yet less obvious effects on understory composition, soil nutrient status, and tree vigor and growth may be equally or more important (Cooper 1960; Dieterich 1983; Fiedler et al. 1992). For example, Biswell (1972) cited fire exclusion as the primary factor inhibiting release and recycling of organically-bound nitrogen (N), a nutrient commonly seen as limiting productivity in ponderosa pine forests (Cochran 1979).

Surface fire is presumed to have a beneficial effect on the vigor and growth rate of ponderosa pine by increasing soil moisture (Haase 1986), recycling nutrients bound in the forest floor (Biswell 1972; Covington and Sackett 1992), reducing inter-tree competition among overstory trees through scattered fire-induced mortality (Cooper 1960), and dramatically reducing the density of smaller trees in the understory (Weaver 1947). Yet the long-term effect of surface wildfires on tree and stand growth has not been examined.

The objective of this study was to compare long-term growth in old-growth ponderosa pine/Douglas-fir stands with and without surface wildfires since 1900. For this study, long-term growth trends were measured by differences in periodic annual increments between extended (≥50-year) intervals before and after 1900.

METHODS

Study sites

Six old-growth ponderosa pine/Douglas-fir stands were found in western Montana that showed no evidence of logging. Three stands were located on the Lolo National Forest, and three on the Bitterroot National Forest. These dry-site stands occur between 1500 and 1800 m elevation on south to southwest-facing slopes. Sample sites were classified within the *Pseudotsuga menziesii*/*Calamagrostis rubescens* habitat type, *Pinus ponderosa* phase (Pfister et al. 1977), the most abundant dry site-type for seral ponderosa pine in western Montana.

Fire history

The fire history of each stand was determined back to approximately 1600 (Fig. 1; Arno and Scott 1992) using fire scar analysis techniques (Arno and Sneck 1977). Two of the Lolo stands (L1 and L2) had experienced surface wildfire since 1900, while the third Lolo stand (L3) and all three Bitterroot stands (B1, B2, and B3) had fire excluded since 1900.

Increment core sampling

A square (100 m x 100 m), one-ha megaplot was laid out in each stand. All trees within each megaplot were recorded by species and diameter at breast height (1.37 m). An increment core was taken 30 cm above groundline from all trees that had established before 1900. Increment cores were extracted using a power borer described by Scott and Arno (1992). Trees were bored repeatedly if necessary to obtain cores that either intersected or came close to the pith. Cores were mounted on grooved boards using methods described by Arno and Sneck (1977).

Increment core analysis

Increment cores were analyzed by counting annual rings with a binocular microscope, and measuring annual radial increments to 0.01 mm resolution using a Technology Dynamics digital tree ring measurement system. Heart rot, pocket rot, and/or pitch inclusions made it impossible to determine age and annual growth increments from some cores, particularly Douglas-fir. Cores for which age could not be accurately determined were dropped from the data set.

Increment cores from each stand were cross-dated using procedures described in Holmes (1983) and Holmes (1992). Cores were discarded if they could not be matched with the master chronology for the period 1842 to 1991. The diameter distribution of cross-dated and discarded trees were compared for

each stand. No systematic differences related to fire history were observed. Consequently, the cross-dated sample was assumed to be an unbiased sample of the population.

Measured radial increments were transformed to basal area increments to compare growth trends among stands, since diameters varied widely among trees within a given stand, and within individual trees over the extended analysis period. Because stem growth occurs after respiratory needs have been met (Gordon and Larson 1968), annual cross-sectional (basal area) increment at breast height is an appropriate measure of growth and vigor (Waring et al. 1980).

Design and analysis

The design of this study is retrospective in that differences in fire history did not result from actively imposed experimental treatments, but rather from variable detection by, or accessibility to, fire-fighters. Because the data are not a probability sample from a well-defined population, inference is limited to the six stands in the sample.

Old-growth trees within a stand are not independent because of competition effects. The degree of spatial dependency is assumed to be negligible, however, because megaplots are large (1 ha) compared to the zone of competitive influence of a tree, and relatively few pairs of trees are in direct competition compared to the total number of possible pairs. Lack of independence does

reduce the effective sample size, however, and we compensate by insisting on very strong statistical evidence before rejecting any null hypothesis.

Statistical analysis

It is hypothesized that fire-exclusion affects the physiological condition of trees by reducing both moisture and nutrient availability, which in return reduces growth and vigor. The general objective of the statistical analysis was to test the hypothesis that post-1900 fire regime had no effect on the physiological condition of old-growth trees as measured by periodic annual basal area increment (PAI). Physiological condition was expected to vary within and between stands, so it was necessary to control or account for pre-1900 condition. Our approach was to use the difference in PAI between two extended time periods as a response variable. Each tree provided an observation on the difference in PAI for a pre-1900 fire-active period (1842-1901) and a post-1900 fire-exclusion period (1942-1991).

The effects of fire exclusion are presumably negligible unless the time since fire is greater than the mean fire interval; however, it is unclear how much time must elapse before there is a significant effect (if any) on growth. For this analysis, the post-1900 response period was selected to begin the year after the longest mean fire interval (52 years) since

burning in any of the six stands. Since the last fire in the pre-fire suppression period was in 1889 in five of the six stands, and the longest mean fire interval was 52 years, the post-1900 response period was selected to begin in 1942.

The response variable in the analysis was the estimated difference between post-fire suppression (1942-1991) and pre-fire suppression (1842-1901) PAI. The 1842-1901 PAI also served as the covariate in the analysis of covariance (ANCOVA). The covariate was assumed to be independent of the fire history factor, and measured without error. Pre-1900 growth is obviously unaffected by post-1900 fire regime, and it is reasonable to assume that measurement error over the long (>50 yr) growth period was negligible. We also assumed that there was no interaction between species and stands.

Stand basal area density (m^2/ha) at the onset of fire exclusion (circa 1900) is an important measure of competitive stress, and a potentially confounding variable when estimating effects of fire regime on post-1900 growth. To reduce the possibility of confounding stand density in 1900 with fire regime effects, analyses were run with and without the two stands (L3 and B3) that had substantially higher 1900 basal area densities than the remaining four stands (L1, L2, B1, and B2).

RESULTS

Stand conditions

All six stands were similar with respect to site conditions based on habitat type classification (Pfister et al. 1977), and four were similar with respect to 1900 basal area density (Table 1).

Table 1. Stand basal area density (m^2/ha) for six old-growth ponderosa pine/Douglas-fir stands in 1900 and 1991. (Adapted from Arno and Scott 1992).

		Lolo			Bitterrroot		
		L1	L2	L3	B1	B2	B3
		m^2/ha					
1900	PP	12.86	11.94	28.24	6.66	12.86	25.94
	DF	2.98	10.33	9.41	11.25	6.20	8.04
	Total	15.84	22.27	37.65	17.91	19.06	33.98
1991	PP	19.06	11.71	30.76	12.40	18.60	16.53
	DF	4.82	8.95	12.63	19.51	10.79	8.26
	Total	23.88	20.66	43.39	31.91	29.39	24.79

PAI Trend

A total of 243 trees passed the cross-dating procedure -- 202 of which had a complete set of PAI's for the 1842-1991 period. Differences in PAI between the fire-excluded period (1942-1991) and the fire-active period (1842-1901) are plotted in Fig. 2. The data are ordered on the x-axis first by stand, and then by 1842-1901 PAI. The values for L1 and L2 are predominantly positive, indicating that nearly all trees in these stands increased in growth in the 1942-1991 period. In contrast, many trees in stands L3, B1, and B2 had substantial decreases in

PAI. Of the 13 trees in stand B3, 10 had positive PAI's; however, all but two of these values were relatively small. The covariate effect is visible in that trees with slower growth in the 1842-1901 period tended to have larger between-period differences.

Differences in PAI for the period 1842-1901 and the periods 1842-1906, 1842-1911, ..., 1842-1991 are plotted in Fig. 2 for each of the six stands. All plots show a long-term increase in PAI compared to the pre-1900 period, since all differences are positive except for a temporary decrease for stand L3 during the period 1931 to 1951. All stands exhibit a decline in the rate of change of differences during the period 1917 to 1941. The post-1941 recovery for L1 and L2 was stronger than that experienced in the other four stands; presumably the slower growth in stands L3, B1, B2, and B3 is attributable to fire exclusion. The stands with the slowest change in growth rate (L3 and B3) also had the highest BA density in 1900. In contrast, L2 had the third highest density in 1900 (22.27 m^2/ha), but its change in growth rate since 1941 was substantially greater than any of the stands with fire excluded.

Analysis of Covariance

The data used in the analysis of covariance were the differences between the PAI's for the 1842-1901 period and the 1942-1991 period. The sample mean PAI differences after

adjusting for 1842-1901 growth are shown in Table 2. The PAI's for the post-1941 period were greater than for the pre-1902 period for nearly all combinations of species and stands. The lone exception was Douglas-fir in stand L3, which had slightly slower growth in the post-1941 period. Without exception, the sample mean differences for stands L1 and L2 were larger than the mean differences for the four stands with fire excluded.

Table 2. Sample mean differences in 1942-1991 and 1842-1901 PAI's, after adjusting for 1842-1991 PAI, by stand and species.

Stand	Species	N	Mean	SE
L1	PP	16	1.12	0.18
	DF	4	1.05	0.24
L2	PP	12	0.93	0.35
	DF	20	0.60	0.15
L3	PP	50	0.21	0.08
	DF	20	-0.03	0.18
B1	PP	13	0.47	0.32
	DF	20	0.01	0.19
B2	PP	22	0.23	0.21
	DF	12	0.59	0.16
B3	PP	4	0.42	0.05
	DF	9	0.43	0.22

The ANCOVA table for the difference in the 1942-1991 and 1842-1901 PAI's is shown in Table 3. There was little evidence of differences between species (F = 1.91; df = 1, 194; P-value = 0.169), strong evidence that the pre-1902 growth rate affects the response linearly, given species and stand (F = 20.04; df = 1, 194; P-value < 0.001), and strong evidence of differences between stands (F = 14.39; df = 5, 194; P-value < 0.001), given species and pre-1902 PAI.

The test for differences among stands was decomposed into three contrasts. The first contrast compared differences in PAI between the two stands (L1 and L2) that have had surface wildfires since 1900. There was little evidence that the population means for these two stands were different [$F = 2.02$; df = 1, 194; p-value = 0.157 (Table 3)]. The second comparison tested the equality of means among the remaining four stands (L3, B1, B2, and B3) that have had no underburning since 1900 ($F = 2.13$; df = 3, 194; p-value = 0.098). The third contrast tested equality of means between the two groups (L1 and L2 vs L3, B1, B2, and B3) with different fire histories ($F = 10.83$; df = 1, 194; p-value = 0.001). Results of these three contrasts provide little evidence of differences in periodic annual growth rate among stands with similar fire histories, but strong evidence of differences in growth between the group of stands experiencing wildfire since 1900 and the group that did not.

Because stand density also influences growth rates, additional contrasts were carried out to compare growth rates between stands with similar BA densities in 1900 (L1, L2, B1, and B2). Results show there is very little evidence of differences in means between stands L1 and L2 (Table 3, discussed previously), or between stands B1 and B2 [$F = 0.08$; df = 1, 194; p-value = 0.776 (Table 4)]. However, there was a significant difference between means of the two groups (L1 and L2 vs B1 and

B2) with different fire histories [$F = 6.26$; df = 1, 194; p-value = 0.013 (Table 4)].

A final test provided virtually no evidence of interaction between species and stands ($F = 1.08$; df = 5, 194; p-value = 0.374).

Table 3. ANCOVA table for the response variable: (1942-1991 PAI) - (1842-1901 PAI). The covariate was the 1842-1901 PAI (× 100).

Source of Variation	DF	SS	MS	F	P-value
Total (adj)	201	146.890			
Species	1	1.124	1.124	1.91	0.169
Stands	5	14.386	2.877	14.39	<0.001
L1 vs L2	1	1.190	1.190	2.02	0.157
Among L3, B1, B2, and B3	3	3.766	1.255	2.13	0.098
L1 and L2 vs L3, B1, B2, and B3	1	6.384	6.384	10.83	0.001
Covariate	1	11.81	11.81	20.04	<0.001
Error	194	114.34	0.5893		

$R^2 = 0.221$

Table 4. Contrasts comparing sample mean differences in PAI between the two Bitterroot stands (B1 and B2) with similar 1900 basal area densities and fire histories (fire excluded); and then comparing B1 and B2 with the two Lolo stands (L1 and L2) which have similar 1900 basal area densities as B1 and B2, but different fire histories (fire active).

Contrast	DF	SS	MS	F	P-value
B1 vs B2	1	0.048	0.048	0.08	0.776
L1 and L2 vs B1 and B2	1	3.691	3.691	6.26	0.013

DISCUSSION

Ponderosa pine/Douglas-fir stands with old-growth trees are not uncommon in western Montana. Typically, these stands are one of three types: 1) stands that were heavily harvested in the late 1800s or the first half of the 1900s, with relatively few old-growth trees remaining; 2) stands that have been entered on a sporadic basis for salvage or high-risk cuttings; and 3) stands that have never been harvested, due either to difficulty of access or to deliberate preservation efforts. Ecologists are particularly concerned about perpetuating stands in the latter two categories, because they support large numbers of old-growth trees. However, many trees in these stands exhibit symptoms of poor vigor, such as flat tops, short or one-sided crowns, and thin, chlorotic foliage with short needles. Individually, low-vigor trees are at risk to the western pine beetle (Dendroctonus brevicomis) and drought stress; collectively, trees in fire-excluded stands are at much higher risk to fire due to unnaturally high fuel loadings and multi-layered structures.

Qualitative indicators of vigor have not been used in a formal way either to compare vigor among stands, or within a given old-growth stand over time, nor are they particularly amenable for such applications. Furthermore, visual symptoms only provide a current reflection of tree vigor, whereas cross-sectional growth increments provide an integrated measure of

vigor and performance at any time in a tree's life. They also allow identification of trends over extended periods.

Based on the long-term and quantitative measure of tree performance that growth increments offer, results of this study provide strong evidence that fire exclusion has a dampening effect on long-term growth rates. The growth patterns reflected in Figs. 2 and 3 suggest that the effect of long-term fire exclusion is slow to manifest itself, which is consistent with the theory that fire exclusion results in gradually increasing competition in both the overstory and understory components, decreased moisture availability due to increased interception, and reduced nutrient availability due to forest floor and down woody material buildup.

Prescribed underburning in ponderosa pine has been shown to have both positive (Morris and Mowat 1958; Van Sickle and Hickman 1959; Pearson et al. 1972)) and negative (Landsberg et al. 1984; Cochran and Hopkins 1990) effects on short-term growth rates. Positive effects are generally attributed to reduced understory competition (Van Sickle and Hickman 1959), increased soil moisture (Haase 1986), and enhanced soil nitrogen status (Covington and Sackett 1992). Based on laboratory leaching experiments using ash from burns in the Douglas-fir/western larch (Larix occidentalis) type in western Montana, Stark (1979) reported that plant ash acts as a sort of time-release

fertilizer. Stark also suggested that periodic fires may produce alkaline soil solutions which enhance chemical weathering of granite and other rocks high in SiO_2.

Negative effects of burning are usually attributed to crown scorch and damage to roots close to the soil surface. For example, Peterson et al. (1991) reported a short-term reduction in Douglas-fir and lodgepole pine growth rates for the first four years following a wildfire. Negative short-term effects of wildfire were attributed to the higher levels of crown scorch resulting from wildfire compared to prescribed fires. The effects of these physical injuries diminish with time, after which the positive effects of burning should obtain. However, Cochran and Hopkins (1990) report somewhat conflicting evidence from a study in central Oregon. They found increased growth rates in fire-excluded second-growth ponderosa pine stands, based on comparisons with yield tables constructed from data reflecting productivity when periodic wildfires were still active on the landscape. They hypothesize generally reduced soil productivity resulting from periodic underburning.

The increased growth of fire-excluded stands reported by Cochran and Hopkins (1990) apparently conflicts with our findings of positive fire effects on long-term growth in old-growth stands, and with the prevailing view of the ecological importance of periodic burning in ponderosa pine. A more complete

complete understanding of the role of fire in ponderosa pine ecosystems is especially important regarding decisions to reintroduce (or suppress) fire, particularly in old-growth stands. This knowledge is critical to the long-term health and perpetuation of a distinctive forest type in the American West.

LITERATURE CITED

Arno, S.F. 1976. The historical role of fire on the Bitterroot National Forest. USDA For. Serv. Intermtn. Res. Sta. Res. Pap. INT-187. 29 p.

Arno, S.F., and K.M. Sneck. 1977. A method for determining fire history in coniferous forests of the Mountain West. USDA For. Serv. Gen. Tech. Rep. INT-42. 28 p.

Arno, S.F. and J.K. Brown. 1989. Managing fire in our forests -- time for a new initiative. J. For. 87:44-46.

Arno, S.F. and J.H. Scott. 1992. Age-class structure of old-growth ponderosa pine/Douglas-fir stands. Manus. in review.

Ayres, H.B. 1900. The Flathead Forest Reserve. 20th Annual Rept. (1898-1899). U.S. Geol. Survey, Part V: 245-316.

Barrett, S.W. and Arno, S.F. 1982. Indian fires as an ecological influence in the Northern Rockies. J. For. 80: 647-651.

Biswell, H.H. 1972. Fire ecology in ponderosa pine grassland. p. 69-97, In: Proc. Tall Timbers Fire Ecology Conference 12. Tall Timbers Fire Research Station, Tallahassee, FL.

Cochran, P.H. 1979. Response of thinned ponderosa pine to fertilization. USDA For. Serv. Pac. Northw. Forest and Range Exper. Sta. Res. Note PNW-339. 8 p.

Cochran, P.H. and W.E. Hopkins. 1990. Does fire exclusion increase productivity of ponderosa pine? p. 224-228, In: Proc. Symp. on Management and Productivity of Western-Montane Forest Soils. April 10-12, 1990. Boise, ID.

Cooper, C.F. 1960. Changes in vegetation, structure and growth of southwestern ponderosa pine forests since white settlement. Ecol. Monogr. 30: 129-164.

Covington, W.W. and S.S. Sackett. 1992. Soil mineral nitrogen changes following prescribed burning in ponderosa pine. For. Ecol. and Mgmt. 54: 175-191.

Covington, W.W. and S.S. Sackett. 1990. Fire effects on ponderosa pine soils and their management implications. USDA For. Serv. Gen. Tech Rept. RM-191. p. 105-111.

Covington, W.W. and S.S. Sackett. 1984. The effect of a prescribed burn in Southwestern ponderosa pine on organic matter and nutrients in woody debris and forest floor. For. Sci. 30: 183-192.

Dieterich, J.H. 1983. Fire history of Southwest mixed conifer: a case study. For. Ecol. Manage. 6: 13-31.

Fiedler, C.E., Arno, S.F., Carlson, C.E., and Harrington, M.G. 1992. Management prescriptions for restoring biodiversity in Inland Northwest ponderosa pine-fir forests. Northwest Envir. J. 8: 211-213.

Gordon, J.C. and Larson, P.R. 1968. Seasonal course of photosynthesis, respiration, and distribution of C in young Pinus resinosa trees as related to wood formation. Plant Physiol. 43: 1617-1624.

Haase, S.M. 1986. Effect of prescribed burning on soil moisture and germination of Southwestern ponderosa pine seed on basaltic soils. USDA For. Serv. Rocky Mtn. For. and Range Exp. Sta. Res. Note RM-462. 6 p.

Habeck, J.R. 1990. Old-growth ponderosa pine-western larch forests in western Montana: ecology and management. Northwest Envir. J. 6: 271-292.

Holmes, R.L. 1983. Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bull. 43: 69-78.

Holmes, R.L. 1992. Dendrochronology Program Library. Lab. of Tree-Ring Research. Univ. Arizona, Tuscon, AR. 35 p.

Keane, R.E., Arno, S.F., and J.K. Brown. 1990. Simulating cumulative fire effects in ponderosa pine/Douglas-fir forests. Ecol. 71: 189-203.

Landsberg, J.D., Cochran, P.H., Finck, M.M., and R.E. Martin. 1984. Foliar nitrogen content and tree growth after prescribed fire in ponderosa pine. USDA For. Serv. Res. Note. PNW-412. 14 p.

Leiberg, J.B. 1899. The Bitterroot Forest Reserve (Montana portion), 19th Annual Report (1897-1898). U.S. Geol. Survey, Part V: 253-282.

Lunan, J.S. and J.R. Habeck. 1973. The effects of fire exclusion on ponderosa pine communities in Glacier National Park, Montana. Can. J. For. Res. 3: 574-579.

Moir, W.H. and J.H. Dietrich. 1988. Old-growth ponderosa pine from succession in pine-bunchgrass forests in Arizona and New Mexico. Natural Areas J. 8:17-24.

Morris, W.G. and E.L. Mowat. 1958. Some effects of thinning a ponderosa pine thicket with a prescribed fire. J. For. 56: 203-209.

Pearson, G.A. 1910. Reproduction of western yellow pine in the Soutwest. USDA For. Serv. Circ. 174.

Pearson, H.A., Davis, J.R., and G.H. Schubert. 1972. Effects of wildfire on timber and forage production in Arizona. J. Range Manage. 25: 250-253.

Peterson, D.L., Arbaugh, M.J., Pollock, G.H., and Robinson, L.J. 1991. Postfire growth of Pseudotsuga menziesii and Pinus contorta in the Northern Rocky Mountains, USA. Int. Jour. Wildl. Fire 1(1): 63-71.

Pfister, R.D., Kovalchik, B.L., Arno, S.F., and Presby, R.C. 1977. Forest habitat types of Montana. USDA For. Serv. Gen. Tech. Rep. INT-34. 174 p.

Ryan, M.G. and W.W. Covington. 1986. The effect of a prescribed burn in ponderosa pine on organic nitrogen concentrations of mineral soil. USDA For. Serv. Res. Note RM-464. 5 p.

Scott, J.H. and Arno, S.F. 1992. Using a power increment borer to determine the age structure of old-growth conifer stands. W. Jour. Appl. For. 7(4): 100-102.

Stark, N. 1979. Plant ash as a natural fertilizer. Envir. and Exper. Bot. 19: 59-68.

Van Sickle, M.S. and R.D. Hickman. 1959. The effect of understory competition on the growth rate of ponderosa pine in north central Oregon. J. For. 57: 852-853.

Waring, R.H., Thies, W.G., and Muscato, D. 1980. Stem growth per unit of leaf area. For. Sci. 26: 112-117.

Weaver, H. 1947. Fire -- nature's thinning agent in ponderosa pine stands. J. For. 45: 437-444.

Weaver, H. 1959. Ecological changes in the ponderosa pine forest of the Warm Springs Indian Reservation in Oregon. J. For. 57: 15-20.

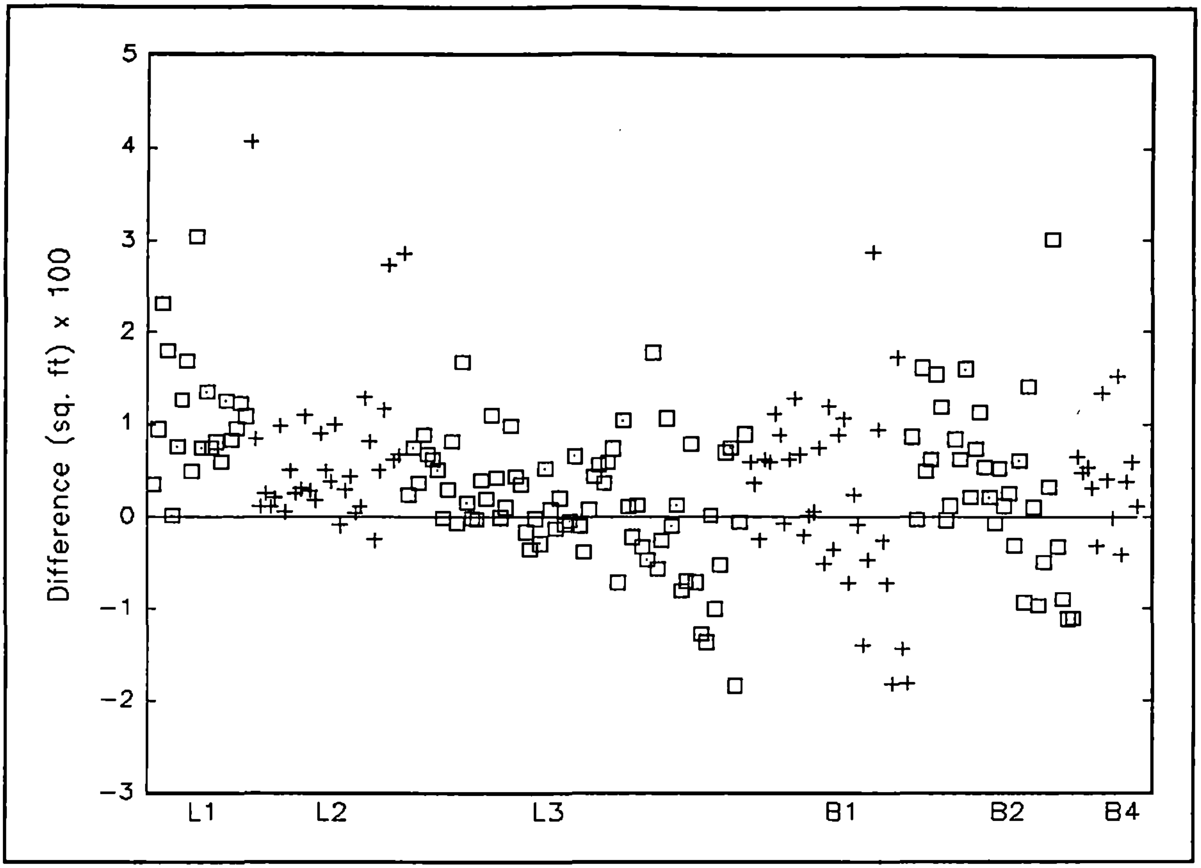

Figure 2. Differences in 1942-1991 and 1842-1901 PAI's, arranged by stand and rank of 1842-1901 PAI. N = 202. Stands are distinguished by alternating symbols.

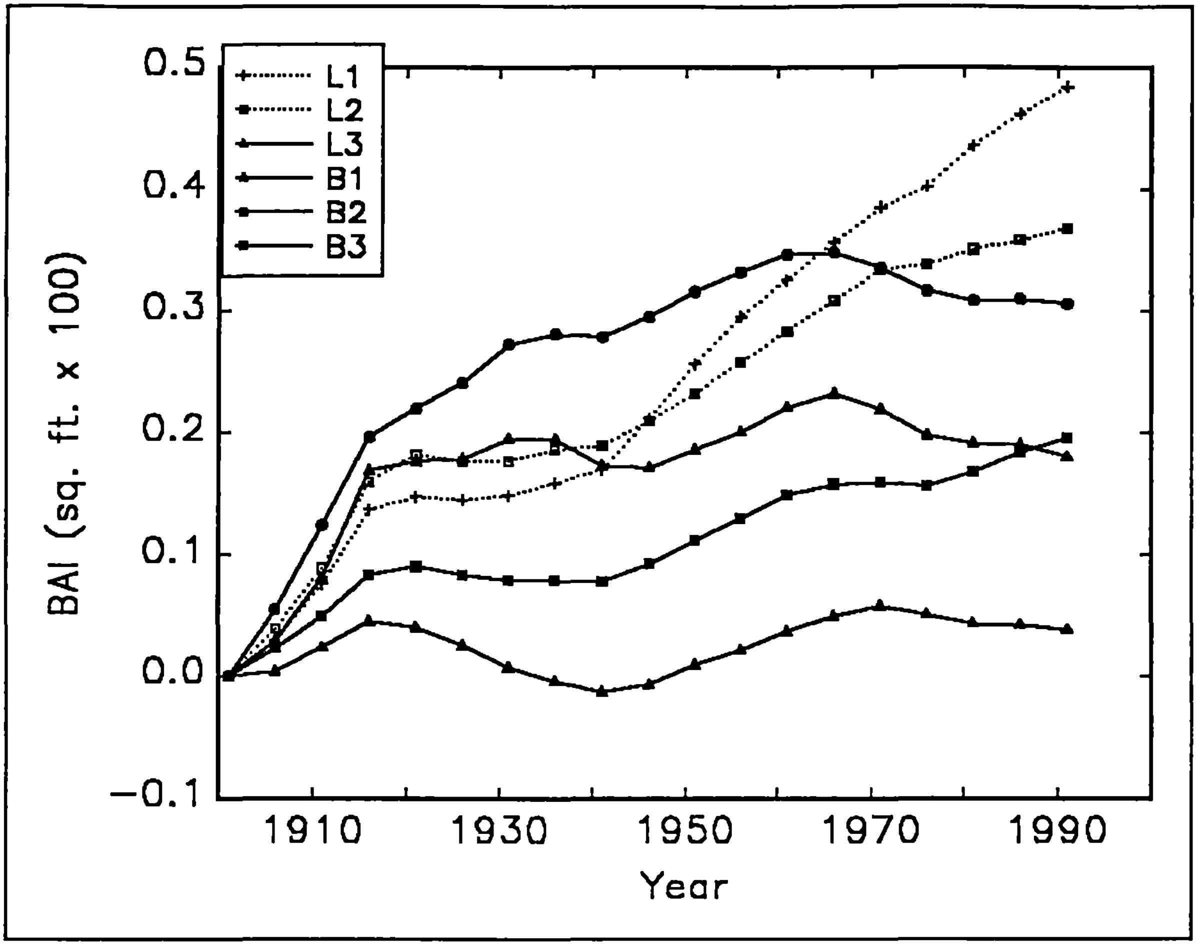

Figure 3. Differences in sample mean PAI between the period 1842-1901 and the periods 1842-1906, 1842-1911,...,1842-1991 plotted against the last year of each iterative period (i.e. 1906, 1911, ..., 1991), by stand.

CEO_FORMATTER Warning.
A decimal tabbed word didn't fit. The tab was expanded to one space.
Error occurred on page 1 , line 15.